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Effects of Furnace Injection of Sorbent for SO2 Control on Electrostatic Precipitator Technology and Requirements

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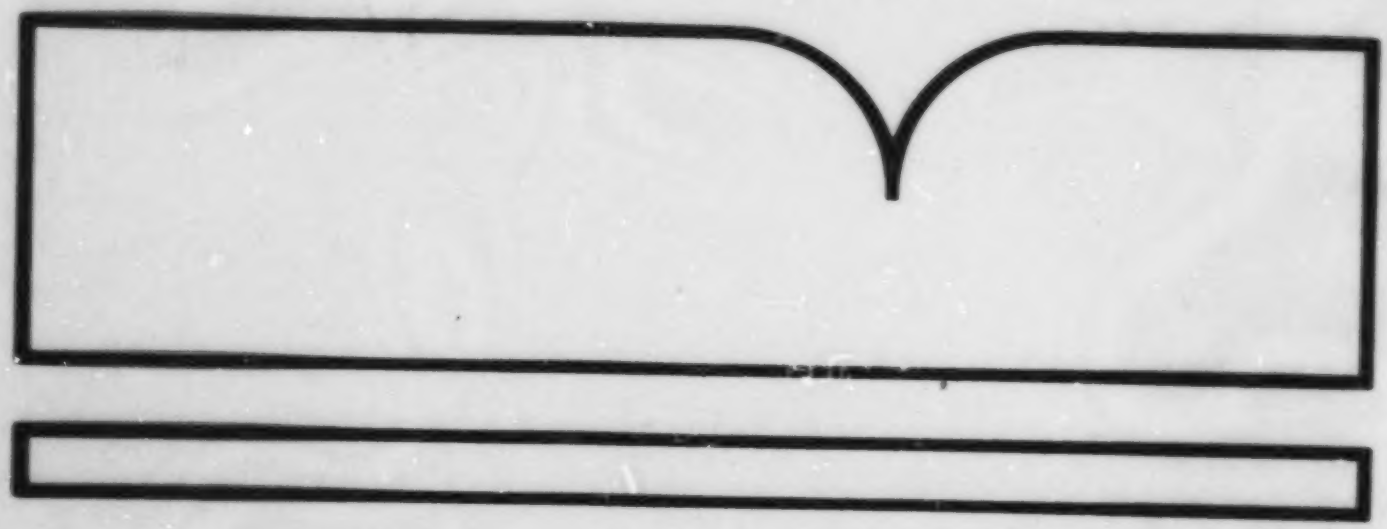

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EFFECTS OF FURNACE INJECTION OF SORBENT FOR SO_2 CONTROL ON ELECTROSTATIC PRECIPITATOR TECHNOLOGY AND REQUIREMENTS

by

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16. ABSTRACT

The paper describes an EPA research program concerning collection of ash/sorbent mixtures. The effects of furnace sorbent injection on the electrical resistivity and the size distribution of particles suspended in flue gas have been measured, using various sorbents and injection modes with a 1 million Btu/hr pilot-scale combustion system. Resistivity was measured both in situ and in the laboratory. It discusses the implication of the results on electrostatic precipitator performance, together with potential corrective measures for improving the collection efficiency of ash/sorbent mixtures.

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ABSTRACT

The EPA research program concerning collection of ash/sorbent mixtures is described. The effects of furnace sorbent injection on the electrical resistivity and the size distribution of particles suspended in the flue gas have been measured. Measurements were performed using various sorbents and injection modes with a 1 x 10^6 Btu/hr pilot-scale combustion system.* Both in situ and laboratory resistivity measurements were made. The implication of the results on electrostatic precipitator (ESP) performance is discussed, together with potential corrective measures for improving the collection efficiency of ash/sorbent mixtures.

INTRODUCTION

The U.S. Environmental Protection Agency is developing a process which employs low nitrogen oxide (NO_x) burners and furnace injection of calcium-containing sorbents to reduce NO_x and sulfur dioxide (SO_2) emissions from coal-fired boilers. This technology is referred to as the LIMB process (for limestone injection with multistage burners). Significant portions of the process development effort are directed toward the objectives of: 1) determining the effects of various types of sorbents and injection modes on the properties of ash/sorbent mixtures that affect ESP performance, and 2) developing technology which will result in acceptable collection efficiency of ash/sorbent mixtures with economically feasible values of specific collection area. This paper describes the EPA-sponsored research program concerning collection of LIMB-generated particle mixtures, presents results from experimental measurements, and discusses the effects of sorbent injection on ESP performance.

*See Appendix 1 for conversion of all English Units used in this paper to Metric Units.

PROGRAM DESCRIPTION

The LIMB particulate research effort consists of laboratory, pilot-scale, and full-scale measurement programs. Laboratory and small pilot-scale work has been underway at Southern Research Institute since July of 1982. A larger scale pilot ESP program (~3000 acfm) is planned for 1985 using a modified version of EPA's mobile precipitator. Full-scale measurement programs are also planned for 1985 at the Weiher Station in West Germany as a part of the United States-German LIMB Technology Transfer Program. Other full-scale measurements with limestone injection using cleaned coal as fuel may be conducted in late 1985 at the Homer City Station of Pennsylvania Electric Company. ESP performance and particulate characterization measurements are also planned for EPA's LIMB Demonstration Program at a full-scale power station during 1987.

This paper is primarily concerned with descriptions of procedures and results from laboratory and small pilot-scale work performed under a cooperative agreement with Southern Research Institute. It was recognized that a meaningful experimental program would require the development of a simulation capability for evaluating the effects of LIMB process variables on the key particulate properties which determine ESP performance: particle size distribution and concentration, and

electrical resistivity. Therefore, the initial phases of the experimental program were directed toward developing a pilot combustion system and operating procedures which produced realistic fly ash properties. Comparisons were made between fly ash characteristics from a 1 x 10^6 Btu/hr pilot-scale system and correlations of fly ash characteristics developed from field measurements on full-scale boilers. When an acceptable level of correspondence between pilot- and full-scale fly ash data was obtained, an experimental program with sorbent injection was initiated. Laboratory and in situ ash characterizations were performed on ash/sorbent mixtures produced while firing an Indiana coal using a staged burner in the pilot combustion system. Simulations of the effect of sorbent injection on ESP performance were performed using a mathematical model with input parameters derived from the pilot-scale experimental program.

EXPERIMENTAL APPROACH

A 1 x 10^6 Btu/hr pilot-scale combustion facility was constructed by Southern Research Institute for conducting studies of emissions control technology and fireside corrosion problems in boilers. Following the initiation of a cooperative agreement research program with the Environmental Protection Agency, the facility was modified so that it would be suitable for performing particulate characterization studies with various modes of sorbent injection. These modifications were:

- Construction and installation of a staged burner for low NO_x firing modes.
- Construction of a specially designed point-plane probe for in situ resistivity measurements.
- Installation of an isothermal residence chamber to simulate the time-temperature interval between an air heater and an ESP inlet.
- Addition of a sorbent feed and injection system.
- Construction and installation of a sulfur trioxide (SO_3) conditioning system.

Figure 1 presents a schematic diagram of the pilot plant. The system includes a refractory-lined furnace which can fire either coal or natural gas at a rate of 0.6 to 1.2 x 10^6 Btu/hr. The furnace is followed by both air- and water-cooled heat exchangers, and by a pulse jet baghouse. A forced draft and an induced draft fan are used so that the system can be operated as a balanced draft unit. System design temperatures and gas velocities for the principal sections are given in Table 1.

The first major experimental task in the research program consisted of particulate characterization studies of fly ash produced by the pilot plant. The objective of this work was to determine if the system produced fly ash which was an acceptable representation of that produced when the same coal was burned in a full-scale boiler. Electrical resistivity and particle size distribution measurements were emphasized because of their importance to ESP performance.

Since resistivity of ash particles is governed by both surface and volume conduction mechanisms, it is appropriate to examine resistivity in the temperature ranges in which each of these mechanisms dominates. The volume conduction mechanism can be evaluated in the laboratory by obtaining fly ash samples from the combustor, and measuring resistivity in the laboratory at temperatures of 200°C and higher. The resistivity values thus obtained can be compared with predicted values from the ash chemical analysis using the predictive method developed by Bickelhaupt.[1] The response of fly ash to moisture and SO_3 can also be evaluated in the laboratory by comparing laboratory values of resistivity with those predicted by Bickelhaupt using a method which includes parameters to represent the effects of water and SO_3. However, comparison of these results with in situ resistivity measurements from the combustor in the 300°F temperature range is complicated by the degree of equilibrium that is attained between the SO_3 and the particulate in the combustion system environment. The laboratory resistivity values represent near-equilibrium conditions, while the in situ resistivity values represent the non-equilibrium conditions in the combustion system at the resistivity port.

As a result of these considerations, it was decided to approach the resistivity simulation evaluation of the combustor as a three-step process: 1) compare laboratory volume resistivity values from combustor fly ash samples with predicted values at hot-side conditions (~600°F); 2) compare laboratory resistivity values with predicted values for 8% moisture, 300°F, and no SO_3; and 3) compare laboratory measured, predicted, and in situ resistivity values in the presence of varying amounts of SO_3 and water vapor at 300°F.

RESULTS

Fly Ash Characterization and Comparison

For the first experiments, a low-sulfur, low-sodium coal, for which an extensive data base was available, was chosen for the fuel. This coal source (South African) was used during an

evaluation performed by SRI of sodium conditioning for a hot-side ESP.[2] Figure 2 compares laboratory resistivity measurements for the ash obtained from the combustor baghouse with those obtained from a full-scale plant burning coal from the same source. Also shown is a predicted curve based on the ash composition from the combustor sample. The ash composition obtained from the coal ash, from the combustor fly ash, and from the full-scale plant (Lansing Smith) is given in Table 2. These comparisons show good agreement between resistivity values obtained on ash samples from the pilot plant and the full-scale plant. The pilot plant fly ash exhibits a resistivity/temperature relationship which agrees with Bickelhaupt's predictor. It should be noted that SO_3 was not a factor in these measurements. Gas analyses on flue gas produced by the combustor indicated less than 0.5 ppm SO_3 at ~300°F in the presence of ~400 ppm SO_2. No SO_3 was used in the laboratory environment.

Table 2 indicates that the combustor fly ash is similar in composition to that obtained during the full-scale field test. A comparison of the coal ash and fly ash chemical composition from the combustor trials indicates that the fly ash is almost identical in composition to the coal ash. This shows that composition-dependent wall losses in the combustor are not a problem for this coal source.

A large amount of experimental work has been conducted on the LIMB program using a high-sulfur Indiana coal, and therefore a supply of this fuel was obtained for experimental work at SRI. Proximate and ultimate analyses of this coal are given in Table 3. Figure 3 shows a comparison between laboratory-measured and predicted resistivity for the Indiana Lot No. 2 fly ash, with 8.1% water in air as the environment. Fly ash samples were obtained from the pilot-plant resistivity probe. All laboratory resistivity determinations were performed in accordance with IEEE Standard 548-1981, using the descending temperature technique. While the comparison of predicted with measured resistivity does reveal differences, the two values never differ by more than a factor of two within the range of temperatures associated with cold- and hot-side ESP's. It should be noted that the coal ash composition is unusual, with both the sodium and potassium concentrations only 25 to 30% of the values usually observed for fly ashes from Eastern U.S. bituminous coals.

Figure 4 shows a family of curves generated with Bickelhaupt's[3] revised model using Indiana No. 2 ash samples, and laboratory data for an air environment containing 21 ppm of SO_3 and 8.1% by volume water vapor. Good agreement is obtained between measured and predicted results. In another test series similar agreement was obtained between predicted and measured results with an air environment containing 7 ppm SO_3 and 8.1% water vapor. In situ data obtained with the Indiana ash gave resistivity values of about 1×10^{10} ohm cm at 300°F in the presence of 25-30 ppm SO_3, whereas the equilibrium laboratory values were more than an order of magnitude lower in the presence of 21 ppm of SO_3. These results indicate that equilibrium conditions were not being approached in the combustion system resistivity probe under the conditions of these experiments. Equilibrium values have been more closely approached in the combustor when water-cooled heat exchangers were employed to reduce the gas temperature at the resistivity port, or when an isothermal residence chamber was installed prior to the resistivity probe. The laboratory results, however, strongly suggest that the combustor produces fly ash with resistivity characteristics consistent with those predicted from a correlation developed from a relatively large data base of ash samples obtained from full-scale plants.

The size distribution simulation capability of the pilot plant was evaluated by comparing the results from impactor measurements performed on the combustor with results from field measurements using identical instruments (Brink impactors). Figure 5 compares cumulative mass loadings obtained from the Lansing Smith plant and from the combustor using two different grinds of coal from the same source. This comparison indicates very good agreement between the pilot-plant and full-scale data sets with a "coarse" coal grind (50-60% through 200 mesh), and fair agreement with a "fine" coal grind (85-90% through 200 mesh) used as a fuel source. Figure 6 shows SEM photomicrographs of fly ash collected on Stage 3 of the Brink impactor used for sampling at both locations. The photomicrograph shows that the combustor was producing spherical ash particles typical of those produced by full-scale pulverized coal boilers. It should be noted that impactor sampling was performed at ~600°F since a hot-side ESP is installed at the Lansing Smith plant.

Size distribution measurements were also performed with the Indiana Lot No.2 coal. Although total fly ash concentration measurements indicated that only about 37% of the coal ash was sampled by the impactors, the upstream losses primarily consist of large particles (>10μm diameter), which would not significantly affect the cumulative mass loadings resolved by impactors. This conclusion is supported by Figure 7, which compares the results from combustor sampling while firing Indiana coal with results from four power plants burning similar coals. This comparison suggests that the combustor is producing somewhat higher concentrations of particles smaller than 10 μm, on an absolute concentration basis, than

the full-scale plants.

If the cumulative mass loadings are converted to a cumulative percentage basis, it is necessary to adjust the cumulative percent from the combustor sampling to account for the dropout which occurs prior to the sampling point. This was accomplished by multiplying the cumulative percentages by the ratio of the predicted total mass loading to the measured value. The predicted total mass loading was obtained for the Indiana coal by using a least-squares fit of field test data developed by Dahlin and Altman.[4] The results of this comparison are displayed in Figure 8, which shows that the combustor generated data, when adjusted for dropout, fall at the upper edge of the data sets for the four plants burning similar coals.

Effect of Sorbent Injection

The process variables for furnace sorbent injection include sorbent type, injection location, calcium-to-sulfur stoichiometry, and furnace design. Since a detailed particulate characterization program cannot be performed with all possible process options, sorbents and injection modes have been chosen for study which have a significant probability of practical application. Most of the data obtained thus far in the particulate program have been with Vicron limestone as the sorbent, although data with a commercial grade of calcium hydroxide, known as Longview hydrated lime, are now being obtained because of the greater effectiveness of the hydrated lime in reacting with SO_2. Characteristics of Vicron and Longview sorbents are given in Table 4.

Figure 9 shows the percentage SO_2 removal obtained in the SRI pilot plant at an injection temperature of approximately 2200°F with Vicron and with two hydrated limes. Although the hydrated limes are more effective than limestone, they are also more expensive on a cost-per-unit-weight basis. Southern Research Institute and the Dravo Lime Company are beginning a project with the objective of developing cost-effective sorbents from limestones. Precalcination, hydration, and the use of promoters to enhance reactivity are approaches which will be evaluated during the course of this project.

Since any furnace injection process will produce mixtures of fly ash and partially sulfated calcine, results obtained with Vicron limestone are expected to be at least qualitatively indicative of the effects of LIMB on ash collectability. Therefore, laboratory and in situ measurements have been made to determine the effects of Vicron injection on resistivity and particle size distribution, and to evaluate the response of the ash/sorbent mixtures to SO_3 conditioning and moisture conditioning.

Figure 10 summarizes in situ resistivity data obtained with Indiana Lot No. 2 coal with and without burner injection of Vicron limestone at a nominal calcium-to-sulfur ratio of 2 to 1. All of the SO_3 concentrations shown on the figure were obtained using a condensation method as described by Cheney and Homolya.[5] No SO_3 was added to the flue gas. The SO_3 concentration variations shown without Vicron addition were obtained by varying the flue gas cooling regime using the water-cooled heat exchangers ahead of the resistivity probe. The lowest level of SO_3 corresponded to the greatest amount of water cooling. For the measurements made with Vicron addition, the SO_3 level was adjusted by varying the amount of excess air used in the furnace. An SO_3 level of <0.2 ppm corresponded to 2.2% O_2 in the flue gas, and an SO_3 level of 7.9 ppm corresponded to 6.5% O_2 in the flue gas.

Several observations can be made from an examination of Figure 10:

- The in situ data at the lower flue gas temperature without Vicron approach the equilibrium resistivity values predicted by Bickelhaupt.
- If no residual SO_3 is present, ash/sorbent mixtures exhibit in situ resistivities of $\sim 10^{12}$ ohm cm.
- Small residual SO_3 concentrations have a dramatic effect on the resistivity of ash/sorbent mixtures. The presence of the sorbent appears to increase the response of the fly ash to a given SO_3 concentration at relatively high flue gas temperatures (~390°F).
- Resistivity values in the range for good ESP operation can be achieved for Vicron/ash mixtures in the presence of relatively low SO_3 residual concentrations, when the source of SO_3 is oxidation of naturally occurring SO_2.

Resistivity measurements have also been made with artificially added SO_3 for conditions that result in negligible naturally occurring SO_3. These measurements indicate that resistivity attenuation can be achieved with the injection of 30-40 ppm of SO_3, but that the residual levels of SO_3 are sensitive to the residence time in the flue gas and the injection temperature, as well as the concentration of injected SO_3. Additional experiments are planned with varying injection levels, residence times, and measurement temperatures.

The residual SO_3 concentrations reported in this paper should be interpreted in view of

the procedures used in the standard SO_3 determination method. A quartz filter at 525°F precedes the condenser, and the SO_3 concentrations are determined downstream of the filter. If any SO_3 is chemisorbed by the solid material on the filter, the concentrations reported will be lower than the actual levels which exist in the flue gas. Consideration is being given to a modified measurement procedure to examine this potential problem.

Laboratory resistivity measurements were performed for Indiana fly ash from the furnace with and without Vicron addition. These measurements were conducted with standard procedures developed by Bickelhaupt. Water vapor concentrations were varied between 7.9 and 18.7% by volume in air, and the SO_3 concentration was either zero or approximately 5 ppm. For the tests involving SO_3, the ash layer and the environment were assumed to be in equilibrium when the resistivity value decreased at a rate of less than 30% in a 24-hr period. Figure 11 summarizes results obtained from these experiments. All ash samples were collected in the combustion system resistivity probe. Table 5 gives a chemical analysis of the ash samples used in the experiments. Several observations can be made from these data:

- The presence of the partially sulfated sorbent increased the response of the ash resistivity to a given SO_3 concentration. This confirms the trend shown by the in situ data in Figure 11. Five ppm of SO_3 in the environment decreased the resistivity at 300°F by over 3 orders of magnitude.

- The ash/sorbent mixture responds to water conditioning, but it appears that temperatures lower than 200°F would be required to lower resistivity into the low 10^{10} ohm cm range with water vapor concentrations of 16-19% by volume, if no SO_3 were present.

- Resistivities of ~2 x 10^{12} ohm cm are measured for ash/sorbent mixtures at hot-side ESP operating temperatures of ~600°F.

Laboratory resistivity measurements have been performed with ash/sorbent mixtures produced with injection of hydrated lime downstream of the burner with the Indiana coal as fuel. Results from these experiments are similar to those shown in Figure 11.

In situ measurements with SO_3 injection for conditioning with hydrated lime sorbent have produced ambiguous results. In situ resistivity values of 3 to 7 x 10^{11} ohm cm in the presence of 1.5 to 2 ppm of residual SO_3 have been observed at temperatures of 270 to 290°F when hydrated lime is injected near the furnace exit. Other data indicate that resistivity values of 3 to 7 x 10^{10} ohm cm in the same temperature range are obtained in the presence of 0.5 to 1.2 ppm residual SO_3 when the hydrate is injected nearer the flame zone. Additional work is planned to define the dynamic relationship between resistivity measurement temperature, injection location for the sorbent, injected levels of SO_3, resistivity, and residual SO_3 levels for both limestone and hydrated lime. The preliminary data suggest that hydrated lime injected near the furnace exit may produce a particulate mixture difficult to condition because of the high reactivity of the unsulfated calcine which remains when the mixture reaches the resistivity port.

A small wire-plate precipitator with conventional electrode geometry has been installed in the pilot plant. Voltage/current relationships obtained with this device will be used to augment the resistivity data in evaluating the effectiveness of SO_3 conditioning. Water conditioning at reduced flue gas temperatures, and other potential conditioning agents, will also be evaluated.

Particle size distribution measurements have been performed using an ultrafine sizing system[6] with Vicron injected at the burner and downstream from the burner at approximately 2200°F. Measurements were also made with hydrated lime injected downstream at the same temperature. The ultrafine system sampled the aerosol from the combustor under conditions which allowed acquisition of the comparative data sets shown in Figures 12 and 13. Figure 12 illustrates that the Vicron has no effect on the concentration of ultrafine particles with diameters below 0.1 μm. In the fine particle diameter range of 0.1 to 0.6 μm, however, the mass concentration was increased by a factor of 3 to 4. Figure 13 illustrates that downstream injection eliminates the fine particle concentration increase observed with burner injection, suggesting that the limestone breaks apart under the intense calcination conditions encountered in the flame zone. Injection of hydrated lime at the downstream injection point produced results identical to those observed with downstream injection of Vicron in the ultrafine size range.

Preliminary Model Simulations

Since downstream injection of limestone generally produces superior SO_2 capture compared to burner injection, without the problem of excessive fine particle production, this mode of sorbent injection was chosen for ESP performance simulations using the EPA/SRI model.[7] The model simulations were performed to evaluate the effects of sorbent addition on ESP performance. The potential effects of ESP design modification and SO_3 conditioning for

counteracting the effects of sorbent injection were also investigated.

A particle size distribution was constructed from impactor and ultrafine data with downstream injection of Vicron limestone. The baseline and with-sorbent distributions are presented in Figure 14, on a basis of cumulative mass per unit volume of gas as a function of particle diameter. Electrical data for the simulations were derived from the following assumptions:

- The fly ash resistivity without sorbent was 2×10^{10} ohm cm.
- Vicron addition produced 2×10^{12} ohm-cm dust without conditioning.
- SO_3 conditioning restored resistivity of the ash/sorbent mixture to 2×10^{10} ohm cm.

The objective of these simulations was to examine the predicted ESP performance for existing and modified ESP's in a specific collection area range likely to be encountered in a retrofit application of LIMB technology. Electrode modifications were simulated which consisted of adding a precharging section with conventional electrode geometry, followed by three collecting sections with 3/8-in. diameter wires with 9-in. plate spacing. These modifications are intended to increase the collection efficiency within the constraints imposed by the existing ESP installation. The ESP mechanical parameters are provided in Table 6, and the electrical parameters are summarized in Table 7. The parameters assumed for the retrofit electrode modifications are given in Table 8. The particle charge values calculated for the precharger exit are similar to those expected at the exit of a cold-pipe precharger that has been developed by Denver Research Institute.[8]

Figure 15 presents the results of the simulations of collection efficiency for the indicated cases, and Figure 16 provides the ESP performance in terms of outlet mass loading ($lb/10^6$ Btu). These graphs show that, as expected, the high resistivity and increased mass loading associated with LIMB sorbent addition produce unacceptably high emissions. If electrical conditions are restored by SO_3 conditioning, the ESP collection efficiency is increased over the baseline case (as a result of space charge and the higher concentration of larger particles resulting from sorbent injection), but the outlet emissions are still approximately 45% greater than the baseline case. However, the two-stage retrofit geometry further increases efficiency and produces predicted outlet mass loadings which closely approach the baseline case.

These simulations must be regarded as preliminary, and they will be repeated when experimental electrical data are available with LIMB-generated particulate for the assumed electrode geometry. Additional simulations are planned for hydrate injection when more definitive in situ resistivity data and particle size data are available for this process mode.

CONCLUSIONS

Furnace injection of calcium-containing sorbents produces high resistivity ash/sorbent mixtures in the absence of small residual concentrations of SO_3. With limestone as the sorbent, resistivity can be reduced to acceptable levels with SO_3 conditioning. If hydrated lime is the sorbent, the in situ response of resistivity to SO_3 is dependent upon the location of sorbent injection in the furnace. With both limestone and hydrated lime as sorbents, the resistivity of the resulting ash/sorbent mixture is reduced to less than 10^{10} ohm cm at equilibrium with 5 ppm SO_3 and 8% water vapor at 300°F. The resistivity of ash/sorbent mixtures produced with limestone injection is also reduced by increasing water vapor concentrations. Additional data are required to define the relationship between in situ resistivity, injected SO_3, and residual SO_3 levels.

Burner injection of Vicron limestone produces large increases in submicron particle concentrations in the 0.1- to 0.6-μm diameter range compared with coal firing without sorbent injection. Injection of either Vicron limestone or hydrated lime near the furnace exit did not produce an increase in fine particle concentrations, as determined by an ultrafine sampling system. Downstream injection of Vicron produced a cumulative mass loading at 10-μm diameter approximately 60% greater than the baseline case at a nominal calcium-to-sulfur ratio of 2 to 1.

Simulations of ESP performance indicate that outlet emissions of less than 0.1 $lb/10^6$ Btu are achievable with sorbent injection at a specific collection area of 300 $ft^2/1000$ cfm if conditioning restores electrical conditions to the values obtained prior to sorbent addition. Modifications of electrode geometry, when combined with a successful conditioning process, have the potential of significantly increasing performance over the values predicted for conventional ESP designs.

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APPENDIX 1

TABLE OF CONVERSION FACTORS

To convert from	To	Multiply by
Btu/lb	joules/kg	2324
foot	meter	0.3048
1 ft^3	$meter^3$	0.02832
ft^2/1000 cfm	$meter^2/meter^3/min$	3.281×10^{-3}
1000 cfm	m^3/min	28.32
grains/ft^3	$grams/meter^3$	2.288
inch	cm	2.54
pound (lb)	kilogram (kg)	0.4536
lbs/10^6 Btu	grams/10^6 joules	0.4302

$°C = (°F - 32)/1.8$

Table 1. System Design Temperatures and Gas Velocities

	Average gas temp, °F	Average velocity, ft/sec
Furnace	2950-2230	4.2
Simulated superheater/reheater	2100-1730	23
Flue gas cooling, refractory-lined section	1730-1525	66
Heat exchanger No. 1 (Air preheater)	1525-890	35
Heat exchanger No. 2	890-595	31
Air-cooled loops	595-362	60
Water-cooled loops	362-260	55

Table 2. Fly Ash Composition Comparison

	Combustor trials		Full-scale plant (Ref. 2)
	Coal ash[a]	Fly ash av	LS-1 sample[b]
Li_2O	0.07	0.08	0.08
Na_2O	0.27	0.28	0.32
K_2O	0.47	0.47	0.44
MgO	1.9	1.9	2.3
CaO	7.3	7.1	8.8
Fe_2O_3	3.6	3.3	5.6
Al_2O_3	36.3	35.4	34.8
SiO_2	43.8	43.0	39.4
TiO_2	1.7	1.8	1.7
P_2O_5	2.8	2.7	2.9
SO_3	0.3	1.6	0.9
LOI	6.1	1.2	12.4

a. Ignited at 1100°C.

b. Analyses performed on ignited samples.

Table 3. Proximate and Ultimate Analyses of Indiana Lot No. 2 Coal

Proximate	Wt. percent
Moisture	8.92
Ash	7.56
Volatile matter	34.23
Fixed carbon	49.29
Btu/lb	12,146
Sulfur	2.29
Ultimate	
Moisture	8.92
Carbon	68.02
Hydrogen	4.42
Nitrogen	0.97
Chlorine	0.43
Sulfur	2.29
Ash	7.56
Oxygen[a]	7.39

a. Oxygen determined by difference.

Table 4. Properties of Vicron Limestone and Longview Hydrated Lime

	Vicron	Longview
Wt. % Ca as $CaCO_3$	98.7	--[a]
Wt. % Ca as $Ca(OH)_2$	--[a]	95.2
Surface area, m^2/g	0.82	16.6
Mass median diameter by sedimentation, μm	15	2.3

a. Not applicable.

Table 5. Chemical Analysis of Indiana Lot No. 2 Fly Ash

	Without Vicron, weight percent	With Vicron, weight percent
Li_2O	0.03	0.02
Na_2O	0.08	0.07
K_2O	0.59	0.35
MgO	0.19	0.44
CaO	0.28	39.4
Fe_2O_3	25.3	12.7
Al_2O_3	26.1	13.8
SiO_2	44.5	25.1
TiO_2	0.91	0.46
P_2O_5	0.07	0.03
SO_3	0.54	7.7
LOI	1.9	0.1

Table 6. ESP Mechanical Parameters

Three electrical sections in the direction of gas flow
Three baffled sections in the direction of gas flow
10% gas sneakage per baffled section, $\sigma_{gas} = 0.25$

Weighted wires in 9-in. ducts
Plate area per section, 26,200 ft^2
SCA, 225 ft^2/1000 acfm at 350,000 acfm at 5.0 ft/s

Table 7. ESP Electrical Parameters

- High-sulfur bituminous coal
  Ash resistivity 2×10^{10} ohm cm at 300°F

Section	kV	nA/cm^2
1	43	20
2	42	29
3	40	30

- Coal and limestone
  Ash resistivity 2×10^{12} ohm cm at 300°F

Section	kV	nA/cm^2
1	30	0.8
2	29	1.2
3	30	2.5

- Coal and limestone, with SO_3 conditioning
  Ash resistivity 2×10^{10} ohm cm at 300°F

Table 8. ESP Retrofit Parameters

- Flue gas conditioning with SO_3
  Ash resistivity 2×10^{10} ohm cm at 300°F
- One precharging section, 2 ft long, with 0.1-in. wires in 9-in. ducts

kV	nA/cm^2
45	50

- Three collection sections, with 3/8-in. wires in 9-in. ducts

Section	kV	nA/cm^2
1	50	10
2	50	10
3	50	10

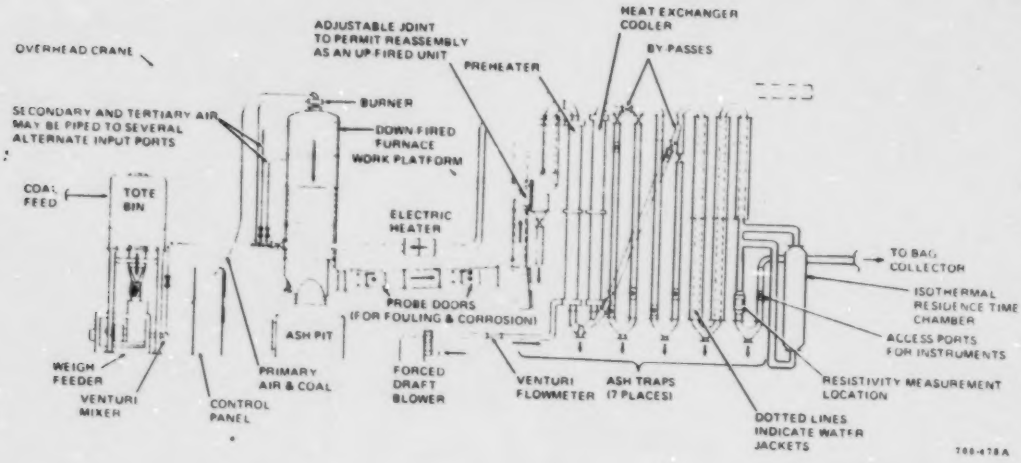

Figure 1. Pilot plant used for particulate characterization studies.

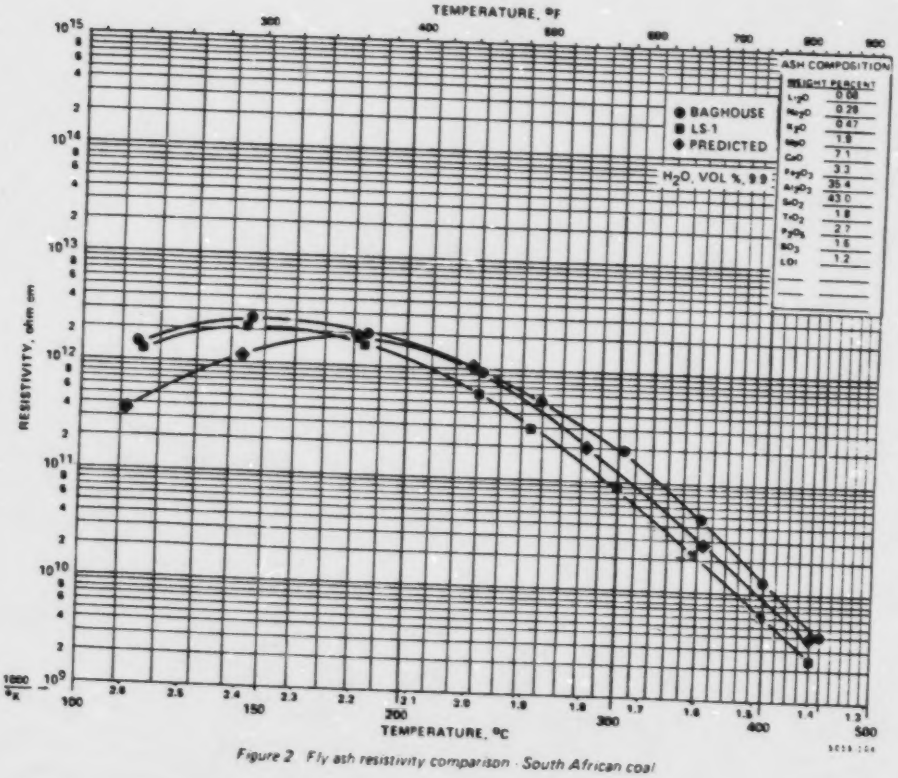

Figure 2. Fly ash resistivity comparison - South African coal

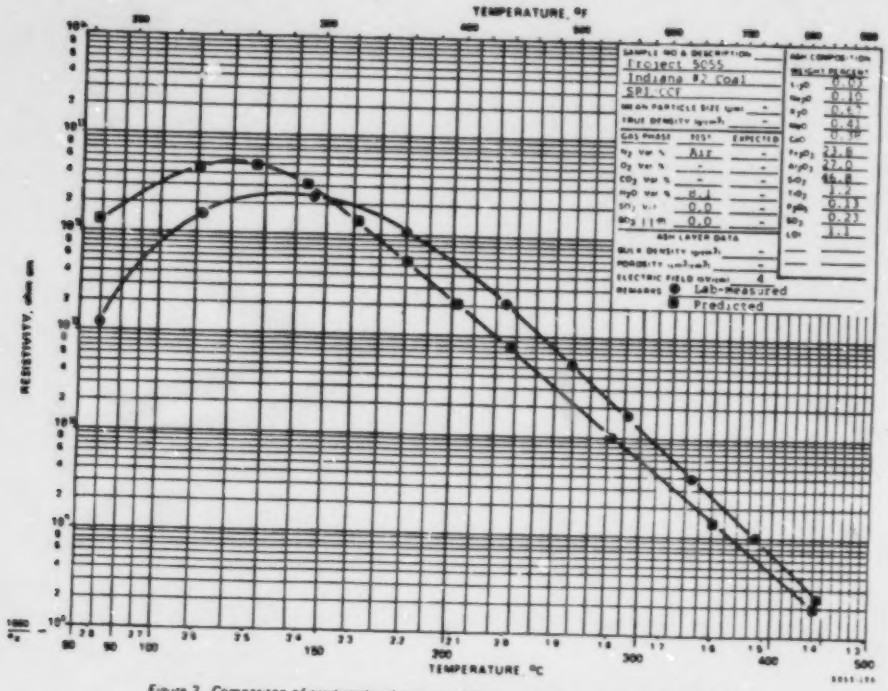

Figure 3 Comparison of predicted and measured laboratory resistivity - Indiana Lot No. 2 Coal

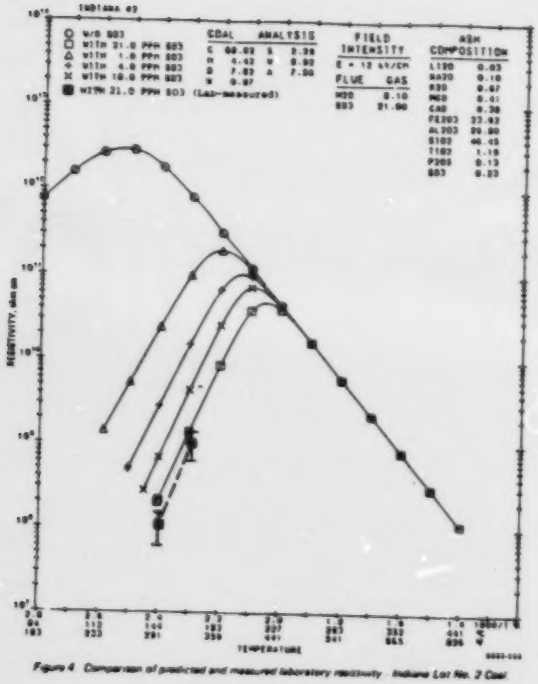

Figure 4 Comparison of predicted and measured laboratory resistivity - Indiana Lot No. 2 Coal

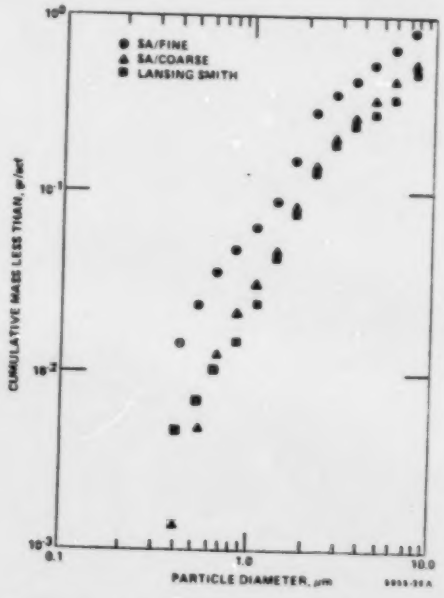

Figure 5. Comparison of size distributions from combustor with that obtained a Lansing Smith Power Plant.

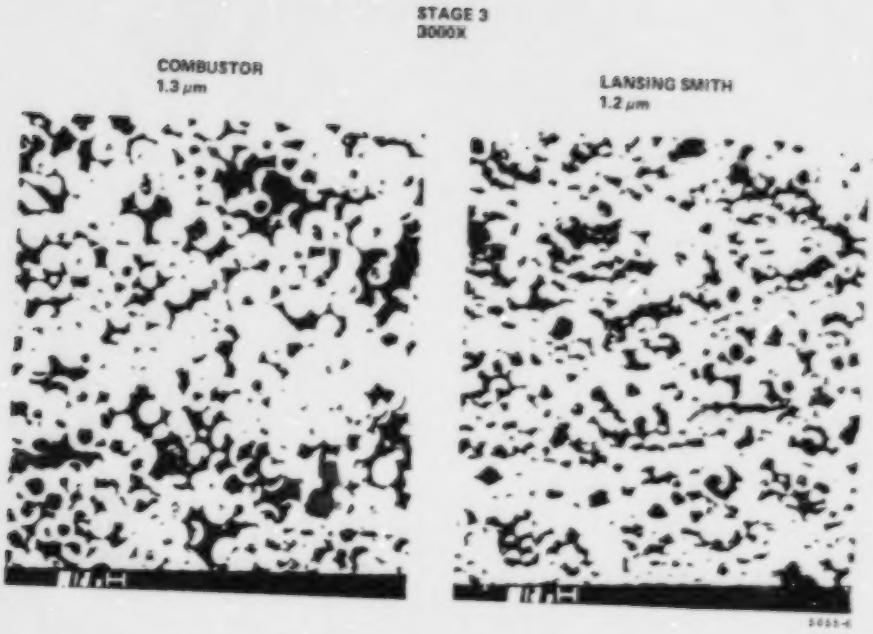

Figure 6. SEM photomicrographs of fly ash collected on Stage 3 at SRI combustor and at the Lansing Smith Power Plant.

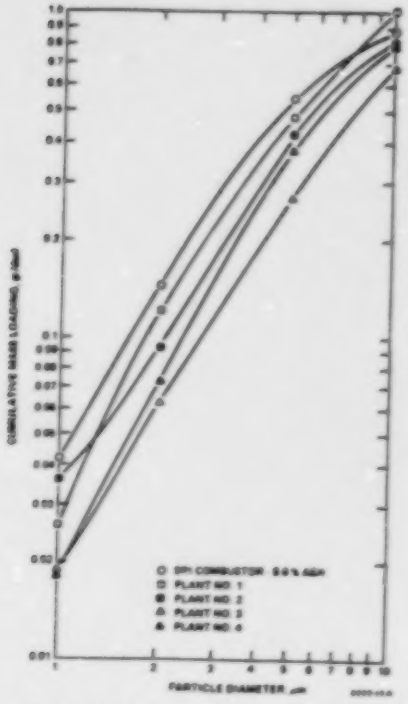

Figure 7. Size distributions from SRI combustor and various field tests.

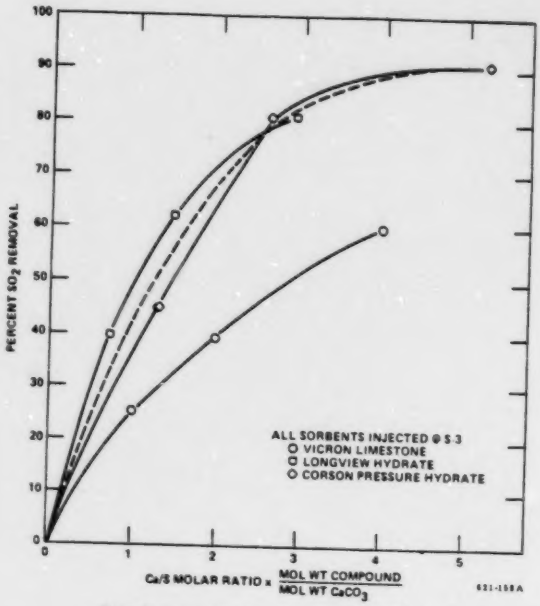
ALL SORBENTS INJECTED @ S:3
VICRON LIMESTONE
LONGVIEW HYDRATE
CORSON PRESSURE HYDRATE
PERCENT SO_2 REMOVAL
Ca/S MOLAR RATIO x MOL WT COMPOUND / MOL WT $CaCO_3$

Figure 9. Comparison of various sorbents on a mass basis.

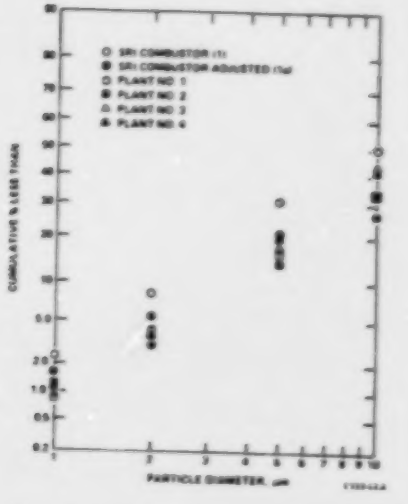

Figure 8. Size distributions from SRI combustor and various field tests.

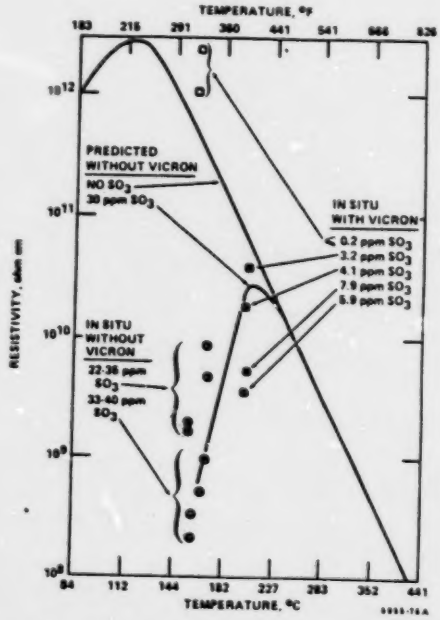

Figure 10. Effect of burner injection of Vicron on the in situ resistivity obtained with Indiana Lot No. 2 coal.

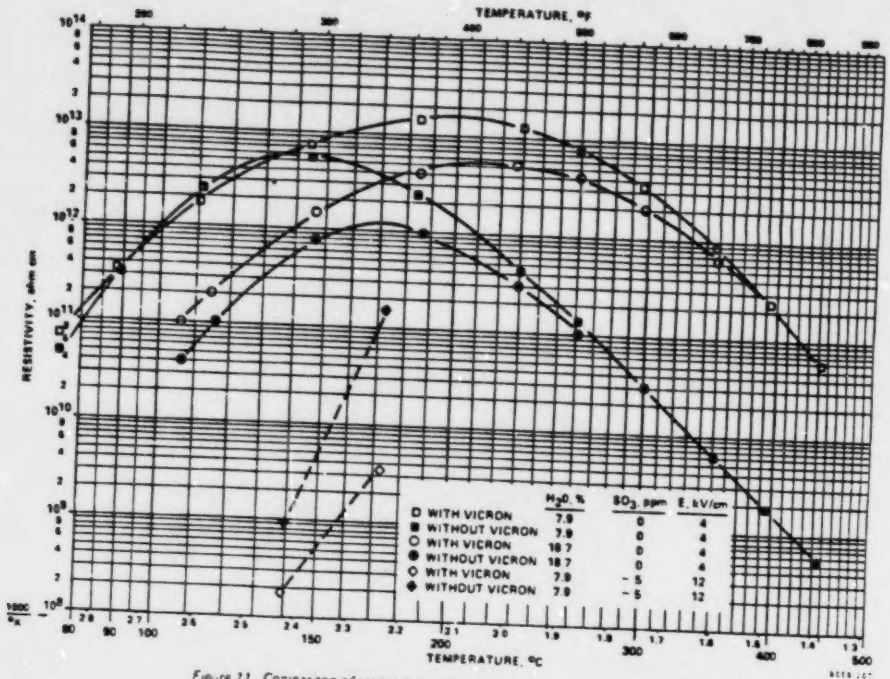

Figure 11. Comparison of resistivities with and without Vicron addition - Indiana Lot No. 2 coal

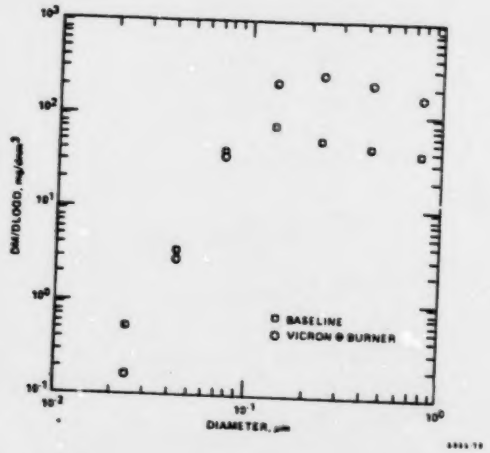

Figure 12. Effect of burner injection of Vicron on the particle size distribution obtained with Indiana Lot No. 2 coal.

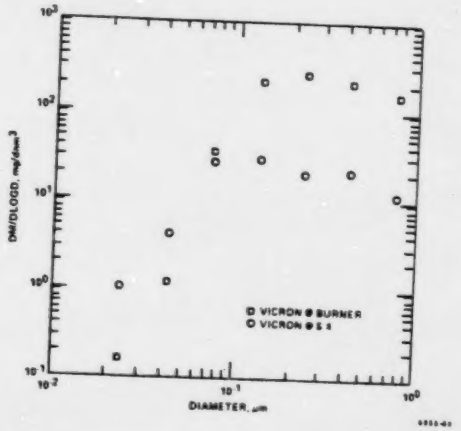

Figure 13. Effect of Vicron injection at S-4 on the particle size distribution compared the effect of burner injection.

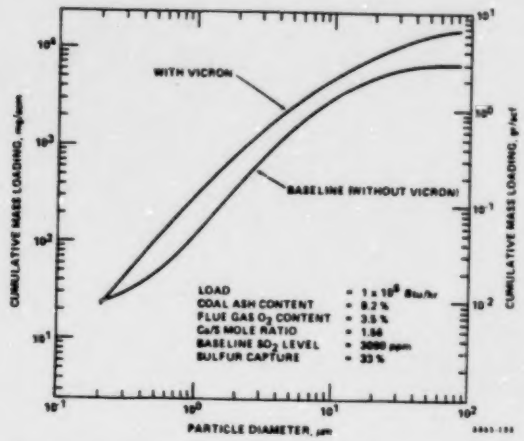
WITH VICRON
BASELINE (WITHOUT VICRON)
LOAD = 1 x 10^8 Btu/hr
COAL ASH CONTENT = 9.2 %
FLUE GAS O2 CONTENT = 3.5 %
Ca/S MOLE RATIO = 1.56
BASELINE SO2 LEVEL = 3000 ppm
SULFUR CAPTURE = 33 %
CUMULATIVE MASS LOADING, mg/sam
CUMULATIVE MASS LOADING, gr/acf
PARTICLE DIAMETER, μm

Figure 14. Comparison of cumulative mass loading curves for Indiana fly ash with and without Vicron sorbent added.

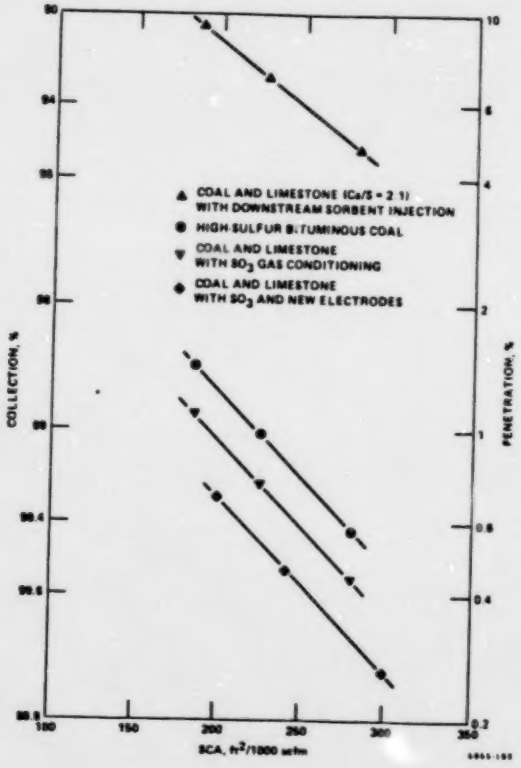
COAL AND LIMESTONE (Ca/S = 2.1) WITH DOWNSTREAM SORBENT INJECTION
HIGH-SULFUR BITUMINOUS COAL
COAL AND LIMESTONE WITH SO3 GAS CONDITIONING
COAL AND LIMESTONE WITH SO3 AND NEW ELECTRODES
COLLECTION, %
PENETRATION, %
SCA, ft2/1000 acfm

Figure 15. Results from ESP model simulation.

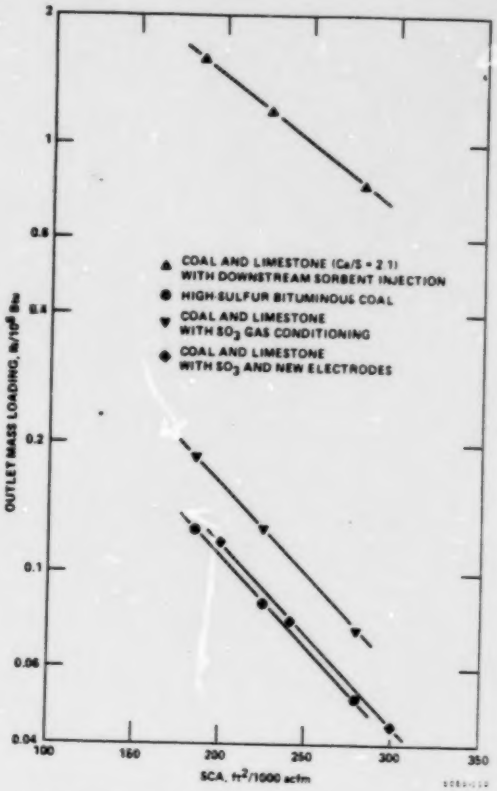
COAL AND LIMESTONE (Ca/S = 2.1) WITH DOWNSTREAM SORBENT INJECTION
HIGH-SULFUR BITUMINOUS COAL
COAL AND LIMESTONE WITH SO3 GAS CONDITIONING
COAL AND LIMESTONE WITH SO3 AND NEW ELECTRODES
OUTLET MASS LOADING, lb/10^6 Btu
SCA, ft2/1000 acfm

Figure 16. Calculated outlet mass loadings from ESP model simulation.